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Converting Wood Volume to Biomass for Pinyon and Juniper

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Abstract—A technique was developed to convert pinyon-juniper volume equation predictions to weights. The method uses specific gravity and biomass conversion equations to obtain foliage weight and total wood weight of all stems, branches, and bark. Specific gravity data are given for several Arizona pinyon-juniper species. Biomass conversion equations are constructed from pinyon-juniper data collected in Nevada. Results provide an interim means of estimating pinyon-juniper aboveground biomass from available volume inventory data.

Keywords: weight, foliage, specific gravity, *Juniperus osteosperma*, *Pinus monophylla*

Pinyon and juniper species dominate about 20 million hectares of forests in the Western United States (Waddell and others 1989). Inventories for these forests commonly report volume and area statistics for wood utilization (Conner and others 1990; Van Hooser and others 1993). Therefore, the volume may be reported only for wood larger than some minimum branch diameter (mbd). These cubic volume, or cordwood, measures are fine if the interest is in fuelwood, but conversions are needed so the data can be used for other ecological purposes.

In ecosystem studies, it is often desirable to describe all organisms with a common measurement. One such measure used to assess trees is biomass or total weight. However, few large-scale biomass studies have produced methodology useful for statewide inventories.

For pinyon and juniper ecosystems, Miller and others (1981) developed biomass equations for singleleaf pinyon (*Pinus monophylla* Torr. & Frem.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little). Few inventory compilations have used these equations because they require diameter and crown measurements that are not commonly available.

In this paper, Miller's data are reanalyzed to construct a method for converting volume (from available volume equations) to total wood and foliage weights. The first step is calculating a 7.6-cm (3-inch) mbd tree weight ($W_{7.6}$) from tree volume and specific gravity. Next, total wood weight (W_0) and foliage weight (W_F) are predicted from $W_{7.6}$. Ample pinyon and juniper volume equations exist to calculate initial volumes (Chojnacky 1985, 1988, in preparation) and to adjust volume to a 7.6-cm mbd if necessary (Chojnacky 1987). Therefore, this paper focuses on specific gravity and total wood and foliage estimation.

SPECIFIC GRAVITY

The specific gravity of wood is defined as a ratio of the density of ovendry wood to the density of water (Forest Products Laboratory 1987). A convenient formula to compute weight from volume is implied in its definition:

$$W = SG \cdot V \cdot D_{H_2O} \tag{1}$$

where

W = ovendry weight (kg)
V = green volume (dm^3)
SG = specific gravity
D_{H_2O} = density of water (1 kg/dm^3).

Barger and Ffolliott (1972) estimated pinyon and juniper specific gravities for wood with bark removed. But these estimates were not appropriate for this study because most pinyon-juniper volume equations predict outside-bark volume (Chojnacky 1985, 1988, in preparation). Instead, this study relies on unpublished specific gravity data from Arizona (table 1).

The data included specific gravities measured from 95 disks cut from lower stems and branches of pinyon and juniper trees throughout northern Arizona. Four

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Table 1—Specific gravity (summarized from Arizona data) for converting volume to weight[1]

Species	Wood and bark combined: Specific gravity: Mean (SG)	Percentiles: 5th	50th	95th	Std. dev.	N	Plots[2]	Raw samples: Mean diameter	Shape[3]: C	H	P	Mean wood specific gravity[4]	Mean bark specific gravity	Wood or bark N
								cm	- - Percent - -					
Juniperus deppeana	0.517	0.485	0.507	0.575	0.029	7	4	16	43	43	14	0.56	0.47	2
J. monosperma	.558	.501	.554	.607	.031	18	15	14	44	44	11	.58	.43	3
J. osteosperma	.523	.459	.525	.574	.034	32	24	14	41	50	9	.54	.45	5
Pinus edulis	.496	.439	.494	.543	.039	38	35	11	87	11	3	.51	.44	8

[1]Volume-to-weight conversion equation:

$$W_i = SG \cdot V_i \cdot D_{H_2O}$$

where

W_i = ovendry wood and bark weight (kg)
V_i = green volume of wood and bark estimated from a pinyon or juniper volume equation (dm^3)
i = 7.6-cm minimum branch diameter for this study, but equation applies to any i
SG = mean specific gravity of wood and bark (from column 2)
D_{H_2O} = density of water (1 kg/dm^3).

[2]Samples from 78 plots in Arizona's Apache (8), Coconino (18), Mohave (22), Navajo (8), and Yavapai (22) Counties.
[3]C = cross section, H = half section, P = pie-shaped section.
[4]Barger and Ffolliott (1972) reported *J. deppeana* = 0.45, *J. osteosperma* = 0.51, *P. edulis* = 0.51.

species were represented—alligator juniper (*Juniperus deppeana* Steud.), oneseed juniper (*J. monosperma* [Engelm.] Sarg.), Utah juniper (*J. osteosperma* [Torr.] Little), and pinyon (*Pinus edulis* Engelm.). Cross-section diameters ranged from 4 to 43 cm. Specific gravity was calculated from a ratio of ovendry weight to green volume for each disk. Green volume was achieved by soaking air-dried disks in water for several weeks. This procedure may have underestimated green volume. Forest Products Laboratory personnel felt that soaking did not appear to completely return the disks to their green volume. The moisture content of the disks when they were sampled should have been maintained.

Because diameters of the sample disks spanned almost 40 cm, the data were examined for a possible relationship between specific gravity and disk diameter. From data graphs, a slight decrease in specific gravity over the range of disk diameters was observed for three species. One species showed a slight increasing trend. However, linear regression slope-tests of the trends indicated they were not significantly different from zero (p-values ranged from 0.20 to 0.93; a p-value of 0.05 or smaller was needed for significance). Therefore, all samples were combined to compute mean specific gravities for each species (table 1, column 2).

The data also included the specific gravity of wood separated from bark for a few representative samples. Even though sample sizes were small, these were included in table 1 (column 13) for comparison to Barger and Ffolliott's data. Specific gravities for the juniper species were higher than Barger and Ffolliott's, but those for the pinyon were similar.

TOTAL WOOD AND FOLIAGE

Miller and others (1981) measured biomass for 72 singleleaf pinyons and 33 Utah junipers sampled from 19 plots in Nevada (fig. 1). The biomass components

Figure 1—Biomass data were sampled from 19 plots.

selected for this study included total weight of all aboveground wood, stems, branches, and bark (W_0), foliage weight (W_F), and weight of wood, stems, branches, and bark for stems and branches larger than 7.6 cm ($W_{7.6}$).

Graphs showed $W_{7.6}$ was a reasonable predictor of both foliage (W_F) and total weight (W_0), but different equation forms were needed to describe them (fig. 2). Foliage weight seemed to approach an asymptote as tree weight ($W_{7.6}$) increased, but total weight (W_0) continued to increase with increasing $W_{7.6}$. Differences between pinyon and juniper species were apparent in the relationship of foliage weight to tree weight ($W_{7.6}$), but were not so apparent in the relationship of total weight to $W_{7.6}$.

Several exponential and growth-form models were fit to the data, but linear regression using a logarithmic transformation (ln or $\log_e$) seemed a sufficient model. Total weight was estimated as:

$$\ln W_0 = \alpha_0 + \alpha_1 \ln W_{7.6} \tag{2}$$

where

W_0 = total ovendry wood, stem, branch, and bark weight (kg)
$W_{7.6}$ = ovendry tree weight to 7.6-cm mbd (kg)
α_0, α_1 = model parameters.

An F-test (Graybill 1976, p. 247) compared a full model (having species distinctions) to a reduced model (with species combined). It showed no need to estimate separate parameters for each species (p-value = 0.83). Therefore, pinyon and juniper data were combined to estimate parameters for equation 2 using linear regression (table 2). Because the largest juniper was less than one-fourth as big as the largest pinyon, these parameters should be used with caution for large juniper.

Foliage weight required an addition to the logarithmic regression model to account for an upper asymptote:

$$\ln W_F = \begin{cases} \alpha_0 + \alpha_1 \ln W_{7.6} & \text{for } W_{7.6} \le X_0 \\ \alpha_0 + \alpha_2 + \alpha_3 / W_{7.6} & \text{for } W_{7.6} > X_0 \end{cases} \tag{3}$$

where

W_F = ovendry foliage weight (kg)
X_0 = parameter (inflection-point) where the two equations join
$\alpha_0, \alpha_1, \alpha_2, \alpha_3$ = other model parameters.

Equation 3 was designed to fit an observed decline in the foliage-to-wood ratio for larger trees. By requiring smooth and continuous estimation at the inflection point (X_0), the number of parameters needed was reduced from 5 to 3:

$$\ln W_F = \begin{cases} \alpha_0 + \alpha_1 \ln W_{7.6} & \text{for } W_{7.6} \le X_0 \\ \alpha_0 + \alpha_1 \left(1 + \ln X_0 - \dfrac{X_0}{W_{7.6}}\right) & \text{for } W_{7.6} > X_0 \end{cases} \tag{4}$$

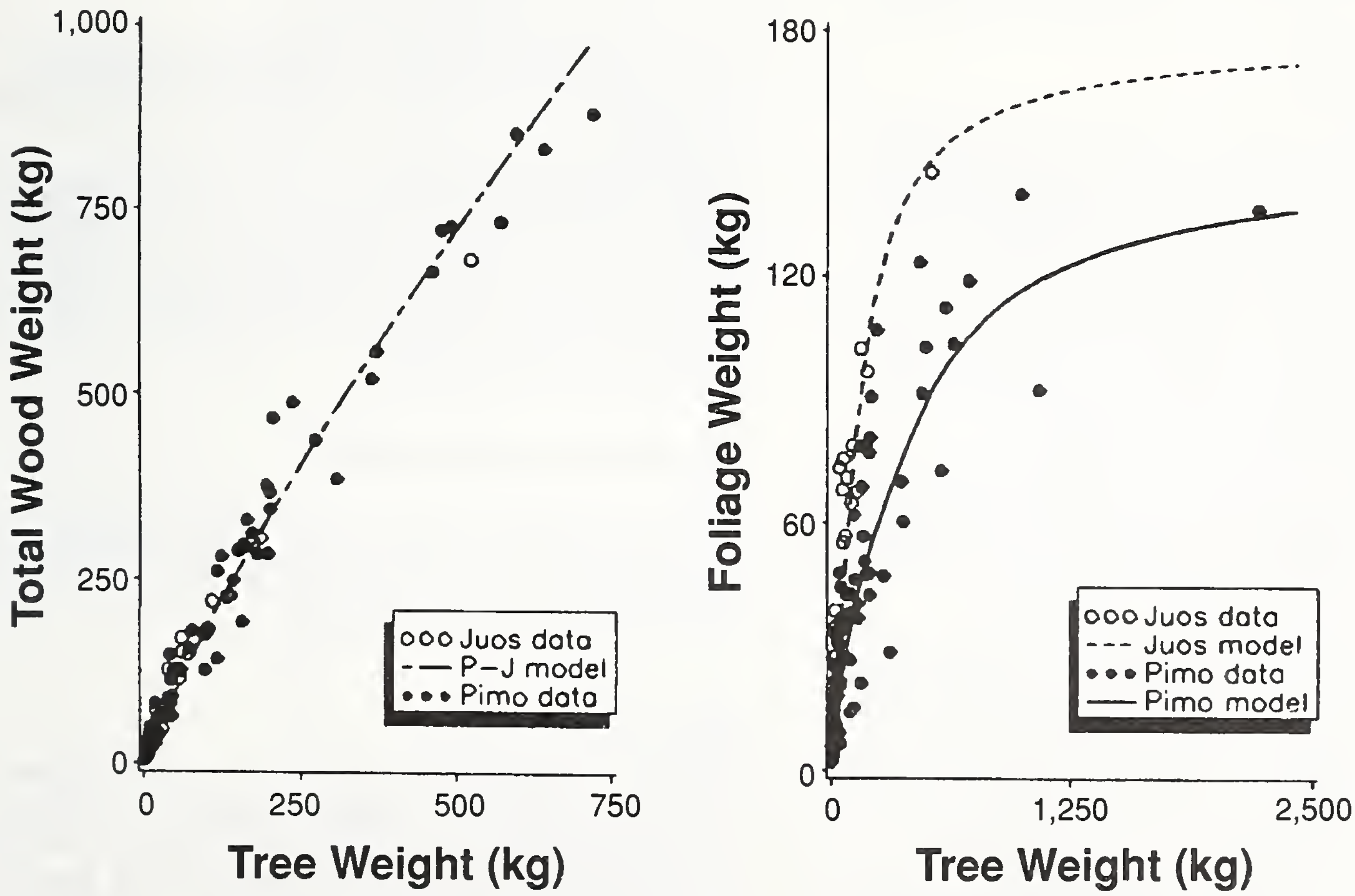

Figure 2—Total wood (W_0) and foliage weights (W_F) were predicted from tree weight to a minimum branch diameter of 7.6 cm ($W_{7.6}$) for *Juniperus osteosperma* (Juos) and *Pinus monophylla* (Pimo).

Table 2—Biomass equation parameters estimated from Nevada data

Biomass component[1]	Species	Parameter estimates α_0	α_1	X_0	Number of trees	Fit statistics R^2	C.V.
							Percent
Wood and bark (W_0)	*Pinus monophylla/ Juniperus osteosperma*	1.3772	0.8384		105	0.99	14
Foliage (W_F)	*J. osteosperma*	1.2867	.6490	150.000	33	.89	27
	P. monophylla	1.0254	.5590	468.028	72	.80	38

[1]Biomass component equations:

$$W_0 = \exp\left[\alpha_0 + \alpha_1 \ln W_{7.6}\right]$$

$$W_F = \begin{cases} \exp\left[\alpha_0 + \alpha_1 \ln W_{7.6}\right] & \text{for } W_{7.6} \le X_0 \\ \exp\left[\alpha_0 + \alpha_1\left(1 + \ln X_0 - \dfrac{X_0}{W_{7.6}}\right)\right] & \text{for } W_{7.6} > X_0 \end{cases}$$

where

W_0 = total ovendry wood, stem, branch, and bark weight (kg)
W_F = ovendry foliage weight (kg)
$W_{7.6}$ = ovendry tree weight (kg) to 7.6-cm minimum branch diameter (mbd) from table 1, footnote 1 equation.

Separate parameters were determined for each species (table 2) because foliage anatomy between pinyon and juniper differs considerably. Data graphs (fig. 2) supported this distinction. Nonlinear regression was used to estimate the inflection point (X_0) for pinyon. Because of convergence problems, the inflection point was subjectively estimated for juniper (X_0 = 150).

CONCLUSIONS

Data from Miller and others (1981) were used to convert pinyon-juniper volume (from available volume equations) to total wood and foliage biomass. The conversion technique required tree weight to a 7.6-cm (3-inch) minimum branch diameter. This was obtained from a volume equation and appropriate specific gravity (table 1). Next, total wood weight (W_0) and foliage weight (W_F) were predicted from 7.6-cm mbd tree weight ($W_{7.6}$) (table 2).

To illustrate the technique, total wood and foliage weight are calculated for a single-stem Utah juniper having 40-cm diameter at root collar and 6.3-m height.

Step 1. Volume predicted to 3.8-cm mbd:

$V_{3.8}$ = 304.9 dm^3 (from table 6 in Chojnacky [1985])

Step 2. Ratio needed to reduce volume to 7.6-cm mbd:

$V_{7.6}/V_{3.8}$ = 0.80 (from equation 11 in Chojnacky [1987])

Step 3. Volume reduced to 7.6-cm mbd:

$V_{7.6}$ = 243.9 dm^3 (step 1 multiplied by step 2)

Step 4. Volume converted to weight:

$W_{7.6}$ = 127.6 kg (from table 1, specific gravity = 0.523)

Step 5. Total wood weight:

W_0 = 231.0 kg (from table 2)

Step 6. Foliage weight:

W_F = 84.2 kg (from table 2).

This conversion technique will also conveniently convert tabulated volumes averaged by diameter class to weight.

Until extensive biomass studies are done, this paper fills a gap in present knowledge by allowing pinyon-juniper biomass to be estimated from commonly available inventory data. Results will be useful for broader ecological interpretation of most past and current pinyon-juniper inventories.

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